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Role of Electromagnetics for Practical Problems

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ABSTRACT

Challenge to the electromagnetics for new applications is discussed. This challenge has become acute due to quickly changing environment prompted by a renewed interest in "radio" engineering. The classical electromagnetic theory is on the verge of changing toward the electromagnetic engineering. Some of the features needed toward this goal is to capture interdisciplinary areas from the electromagnetics point of view. They include close couple to microelectronics, computer engineering, and system applications. Several subjective views and examples will be presented.

INTRODUCTION

For quite some time, the electromagnetic field theory has been considered to be a mature subject without much excitement except for those individuals, typically academics, directly involved with the subjects. In many instances, the problems typically dealt with, particularly in the academic community, have been neither theoretical nor application oriented. What is often called the theoretical paper has actually not dealt with the theory but analytical and/or numerical exercises. There have been very few fundamental theoretical developments throughout the history of electromagnetics. Many "theoretical" papers have dealt with pre-solved problems by other means or improved methods.

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It is somewhat fortunate that the arrival of the renaissance of radio engineering due to a significant increase in interest in personal and mobile communications and intelligent automobile and highway technologies all over the world coincides with the need for the dual use of microwave technology in the U.S. and other parts of the western world. Government and industries in the U. S. have invested a large sum of resources in microwave and millimeter-wave technologies mainly for military use. Some countries, typically Japan, have advanced this segment of technology essentially through commercial and other non-military applications. Both sides need to learn from experiences of the other in many respects for realization of dual use technology. The dual use of the technology must be appealing to a greater segments of engineering community with relative ease. This is a significant challenge to technology which must provide a low cost solution to many complicated problems . One key element is the enhanced role of electromagnetics. This is because the electromagnetics is fundamental to any design of microwave and millimeter-wave structures. However, the electromagnetics community must provide a swift solution to practical problems, which may be far from the idealized "theoretical" problems. In order to accomplish this assignment, the role of electromagnetics must be enhanced by making its process more cost effective, more responsive to real world problems by importing the recent advances in computing technology, more interaction with related subjects such as microelectronics and nonlinear phenomena so that the "electromagnetic engineering" must emerge.

As the new era starts, more innovative technology, more cost effective applications of existing technology and exploitation of higher frequencies are being discussed. Significant opportunities exist for those engaged in electromagnetics if they recognize the changing needs and evolve into a new

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expanded electromagnetics. Some representative elements needed for this change will be described in this paper by way of several examples.

INTERACTIONS WITH ACTIVE DEVICES

When the research of vacuum tubes was in progress during 1940's and 50's, the interaction of electromagnetic fields with the electron beam was one of the thrust areas of electromagnetics, or more correctly electrodynamics. The same level of interest and intensity in research has not taken place in the case of solid state circuits. Typically, the solid state devices are treated as lumped elements represented by S parameters. It is on the other hand well recognized that the passive elements are considered as distributed elements and characterized as such. Although they may be represented by lumped element models, this is done after electromagnetic analysis.

The interaction of the electromagnetic wave with active devices needs to be considered carefully and must be understood well in the new microwave circuits yet to be proliferated. As the cost effectiveness is emphasized in the coming dual use technology, it is desirable to design the entire circuit with a single design process. For such a purpose, the enhanced electromagnetics should play an important role. The wave-device interaction must be taken into account. An example is the active antenna. The antenna acts not only as a radiating element but also provides a circuit function such as diplexer or resonator. This latter function becomes an integral part of the active circuit such as the oscillator.^{1,2} Fig.1 shows an example of active antenna. The patch antenna is not only a radiating element but also a resonant feedback element for the active device to form an oscillator. The structure is a two-element array. In this arrangement, the radiation pattern can be switched from the difference pattern to the sum

pattern. It is well known that the antenna is one of the bottleneck issues for personal communication. The concept of an active antenna can add some "intelligent" function right at the antenna. The design and analysis of this type of circuits must be enhanced. Some efforts are described in the next section.

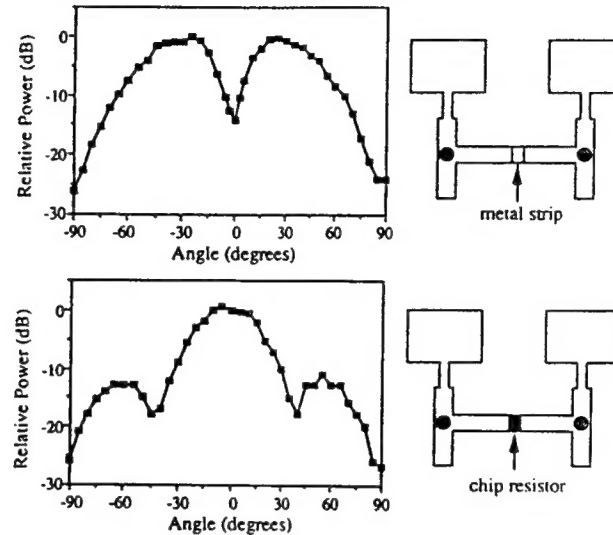


Fig. 1 Two element switchable active antenna

NEW DIRECTIONS OF NUMERICAL ELECTROMAGNETICS

As the operating frequency is increased and the packing density is increased in the integrated circuits, interactions among the circuit elements and between the chip and the environment needs to be the integral part of the analysis and design. At the moment, most of the CAD software treats the passive and active components separately and environmental effects such as packaging issues are not well integrated. This lack of coordination will be fatal for next generation of the microwave and millimeter wave integrated circuits or chips which may be multifunctional. The cost reduction of such complex structures is enormous challenge and is particularly important for commercial applications. The design cycle must be reduced and the chance of the first path design success must be

enhanced. Hence, all of these effects mentioned above need to be addressed and attacked simultaneously in an integrated and coherent fashion.

Even the numerical techniques for passive components alone are numerous, ranging from the integral equation type to differential equation type and from frequency domain techniques to time domain techniques. Most integral equation types including the spectral domain method require highly analytical preprocessing and reduced computational effort.³ On the other hand, the time domain method such as FDTD and TLM requires minimal amount of analytical preprocessing while a large memory and a long computation time are required.^{4,5} These facts precluded the extensive use of these time domain methods until recently. Ever increasing computational power provided popularity of these time domain method recently.

One of the appealing features of the time domain methods as applied to a practical problem is that they provide good physical insight on the wave phenomena in a complicated circuit structure by way of easy visualization which is evolving in time. However, their greatest appeal, in the opinion of the author, is its potential to model the entire circuit including the active devices and packaging effect, although not enough has been done in these areas. It is noted that many active device characteristics are formulated in the time domain. Therefore, their characteristics can be integrated into the methods such as FDTD. A recent effort along this line has provided a remarkably interesting results as shown in Fig.2. In this figure, the active antenna shown in Fig.1 is modeled in its entirety by the FDTD with the device under the large signal condition.

It is clear that the results are very useful for visualizing the wave

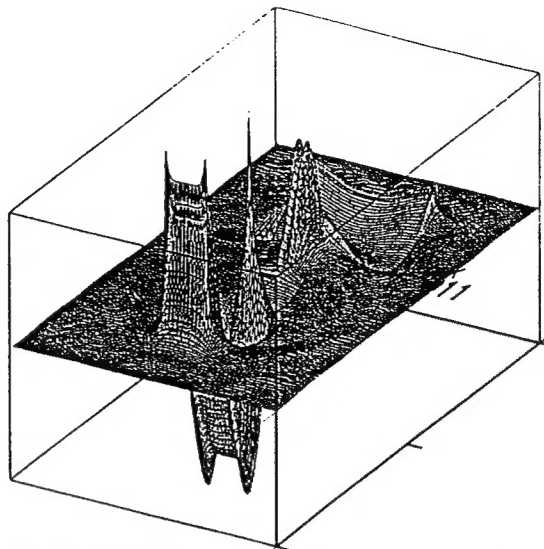


Fig.2 FDTD results of active antenna

phenomena in a practical circuit. Another useful feature of the FDTD and TLM is that they are very well suited for parallel computation machine, because the space calculations are quite localized. Nevertheless, there still remain a significant effort to make these methods computationally efficient. For instance, in many circuits, the major computational volume is spent for the passive structure which are not nonlinear. Therefore, such a subarea may be replaced by the terminal characteristics of its interface with active devices. This concept can be accomplished by the use of Diakoptics which is essentially the time domain numerical Green's function.⁶

PACKAGING AND MULTIMODING EFFECTS

Recently, the effect of packaging has drawn attention in the circuit design. In many cases, the packaging effect implies the deviation of the designed circuit characteristics when the circuit is placed in a package. However, the packaging effect needs to be interpreted in a wider sense. Multilayer configuration and flip chip mounting are just two examples related to the packaging technique and need to be characterized as such.

In addition, in a highly complicated circuit configurations particularly those involved with multilayers, possible existence of undesired "modes" needs to be recognized. One of the highly publicized phenomena is the lateral leakage in a planar transmission lines such as the conductor backed coplanar waveguide or slot line.⁷ This leakage is essentially due to the parallel plate TEM modes and is now well understood. Although this leakage is detrimental in many cases, a possibility of making use of such a leakage phenomenon and constructing a possible new component has been reported.⁸ Fig. 3 shows an example of directional coupler which takes advantage of the leakage mechanism.

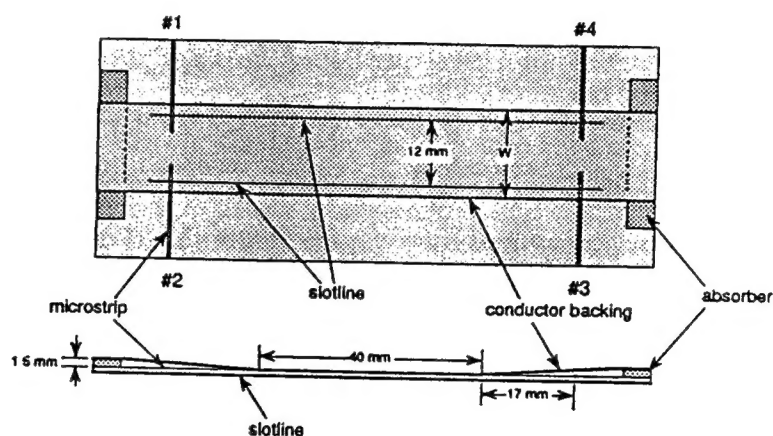


Fig. 3 Directional coupler using the leakage mechanism

CONCLUSIONS

Some examples were presented from the point of view of new directions needed for electromagnetic engineering which can attack practical microwave problems required in the dual use technology.

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